Relative Effects on a Low-Volume Road System of Landslides Resulting from Episodic Storms in Northern Idaho

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In late November to early December 1995 and February 1996, northern Idaho was hit by heavy rains on a deep snowpack, resulting in two flood and landslide events of historic magnitude. Each of these storms was larger than the previous significant storm, which occurred in January 1974. A study was initiated by the U.S. Department of Agriculture Forest Service to survey and study the effects of the resultant landslides on the Clearwater National Forest, including the effects on the aquatic ecosystem. The results of this study were compared with the estimated average natural sediment resulting from landslides to evaluate the incremental impacts of these recent episodic landslides. They were also compared with the results of a study conducted on the landslides resulting from the January 1974 storm to determine if the landscape was responding more severely to large storms as a result of Forest Service management activities over the past 21 years. The general results of this study indicate that, of the Forest Service management activities, roads are the major contributor; however, they contribute less sediment than natural landslides. The total resultant sediment appears to be within the transport capacity of the aquatic system, and the landslide response in 1974 was similar to the 1995–1996 response. The results of the aquatic ecosystem study were generally mixed, with some habitat parameters indicating degradation, some unchanged, and some improved as a result of the flooding or flooding with landslide sediment.

In late November to early December 1995 and February 1996, northern Idaho was hit by heavy rains on a deep snowpack, resulting in two flood and landslide events of historical magnitude—each the largest since January 1974. Many low-lying areas were evacuated and sustained extensive public and private property damage (*1*). Fifteen northern Idaho counties, including Clearwater County, were declared flood disaster areas. A study was initiated by the U.S. Department of Agriculture (USDA) Forest Service to survey and study the effects of landslides on the Clearwater National Forest (CNF), including the effects on the aquatic ecosystem. The final report of this study is the *Assessment of the 1995 and 1996 Floods and Landslides on the Clearwater National Forest* (*2,3*). This paper summarizes that final report.

STUDY AREA

The CNF is located in Clearwater, Benewah, Shoshone, Idaho, Lewis, and Latah Counties in north central Idaho (Figure 1). It lies west of the Montana border and is bounded on three sides by four other national forests: the Lolo in Montana, the Bitterroot in Montana and Idaho, the Nez Perce in Idaho, and the St. Joe in Idaho. The forest boundary encompasses all or major portions of the drainages of the north and middle forks of the Clearwater River, the Lochsa River, and the Palouse River, which are all part of the Columbia River system.

METHODS

Landslide Assessment

Field and aerial photograph inventories were necessary to obtain complete coverage of the CNF. The entire forest, with the exception of the Palouse district and the Selway Bitterroot Wilderness, was flown in July 1996 and photographed at a scale of 1:15840.

A threshold landslide volume of 19.1 m^3 (25 yd^3) was established because of the difficulty of estimating landslide volumes from aerial photography and because of the difficulty of field measurement of the typical debris slides, which alternately scoured and deposited material as they progressed downslope. Because of these volume measurement problems, the landslide volumes were grouped in volume ranges. Estimation of the sediment delivered to a stream was made more difficult because some of the sediment was likely removed by spring runoff. Sediment delivered was grouped in percent delivered ranges.

Volume estimates from field surveyed landslides were used to calibrate aerial photograph volume estimates on approximately 10 percent of the aerial photograph interpreted landslides. It was found in an Oregon State Forestry Department study (*4*) of landslides in western Oregon that locating landslides through aerial photography in forested areas significantly undercounts the number of landslides occurring under a dense tree canopy. On the basis of the experience of the author performing the aerial photograph interpretation and another author's experience in that area of western Oregon, it was concluded that the CNF canopy cover should not have interfered significantly with landslide identification.

Landslides were classified into four land use categories: road, timber harvest, fire, and natural. The road category was defined as a landslide originating between the top of a road cut and 30.5 m (100 ft) below the base of the road fill. Landslides attributed to timber harvest include landslides on areas varying from recent clearcuts to 50-year-old timber stands. Fire was considered the land use if the area had been burned by a wildfire during the preceding 10 years. A landslide

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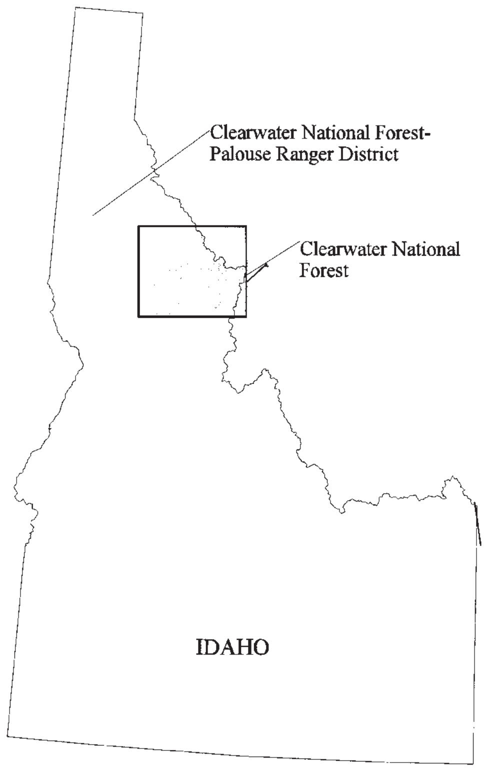


FIGURE 1 Study location.

not originating in any of these three categories was considered of natural origin.

Stream Assessment

Two sets of comparisons were made to estimate stream response to the 1995–1996 landslides:

- Comparison of 1996 postlandslide conditions for 5 stream habitat parameters on 16 streams with the results of the early 1990s annual condition surveys on the identical stream reaches. This comparison provided a temporal, or before-and-after, comparison.
- Comparison of 1996 data for 44 stream habitat parameters and biota parameters on 35 stream reaches that had been affected by flood and landslides, or had at least experienced flooding because all of the CNF streams had experienced the flooding.

RESULTS

Storm and Flood Conditions

The Clearwater River drainage experiences periodic floods and landslide events. Major floods occurred in 1919, 1933, 1948, 1964, 1968, and 1974, with stream flow records for all but the 1919 event.

The vast majority of the landslides of the winter of 1995–1996 resulted from a series of storms in late November to early December and early February. The total precipitation on the CNF for the November to December series was approximately 200 percent of average, with approximately 152.4 mm (6 in.) of precipitation in 6 d, and the February series averaged 114.3 mm (4.5 in.) of precipitation in 6 d.

Stream flows for the February event were higher because of more snowmelt. High flows were not as severe in the two drainages at higher elevations (Lochsa and Selway) as in the drainages at lower elevations (Clearwater and North Fork Clearwater). Some streams experienced their largest flow on record, depending on elevation, snowpack, and drainage location. Additional landslides did occur during the spring snowmelt, although the stream flow rates were not unusually high.

Landslide Assessment

A summary of the data gleaned from the landslide study database is presented in Figures 2 through 4 and Tables 1 through 7. Landslide risk factors of geologic parent material, landform, elevation, hillslope aspect, and hillslope steepness were distilled from the data analysis.

The volume estimates presented in the figures and tables are the authors' best estimates. Both total and delivered volumes for each land use were given ranges during the analyses. The best estimate of the total volume displaced was 535 500 m^3 (700,000 yd^3), with a range of 306 000 m^3 (400,000 yd^3) to 688 500 m^3 (900,000 yd^3). The best estimate of the volume delivered to streams was 306 000 m^3 (400,000 yd^3), with a range of 229 500 m^3 (300,000 yd^3) to 535 500 m^3 (700,000 yd^3). Two large landslides, which were judged to be natural, had a combined volume of 229 500 m^3 (300,000 yd^3) and contributed 43 percent of the total estimated landslide volume.

According to the authors' observations, a majority of the landslides in the less than 10 percent delivery category did not actually deliver sediment to a stream or floodplain. It should be noted that the minimum volume threshold of 19.1 m^3 (25 yd^3) should not have introduced a significant error in total volume because even 1,000 additional landslides of 19.1 m^3 (25 yd^3) would have accounted for only 19 100 m^3 (25,000 yd^3), or less than 4 percent of the best estimate of total landslide volume for the 1995–1996 events.

The timber harvest landslide data include landslides on areas with 40- to 50-year-old stands of regenerated timber that should have fully recovered root strength (*5*).

A possible reason for the low incidence of fire-associated landslides was that the CNF had experienced few wildfires over the past 10 years at elevations below 1524 m (5,000 ft) on unstable landforms.

Table 1 shows that Border and Batholith parent materials accounted for 84 percent of the landslides for all land uses.

Table 2 indicates that 94 percent of all landslides occurred below elevations of 1524 m (5,000 ft), which coincides with an abrupt change in soil- and land-forming processes on the CNF. The soil-forming processes are primarily driven by chemical weathering below elevations of 1524 m (5,000 ft) and physical weathering with frost churning above elevations of 1524 m (5,000 ft), which suggests that these storm and landslide events are an integral part of the geomorphic process and result in a landscape susceptible to landslides.

The most landslide-prone slope aspects of south through west are consistent with the normal winter storm track into northern Idaho from the Pacific Ocean. The slopes with these aspects also receive the highest solar energy input, resulting in warmer, wetter snowpacks that are available for melting by a relatively warm, wet storm.

Table 5 indicates that the Breaklands and Mass Wasting landforms are most susceptible to landslides, which is not surprising because the Breaklands are generally very steep and the Mass Wasting landform is intrinsically unstable.

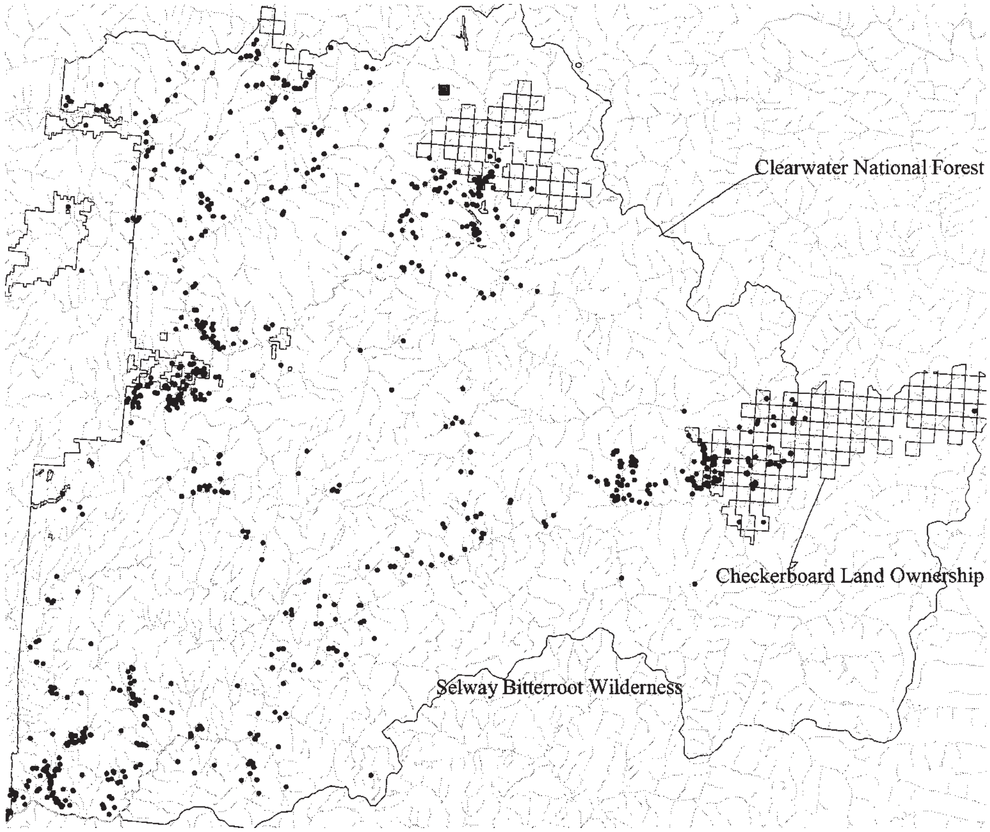
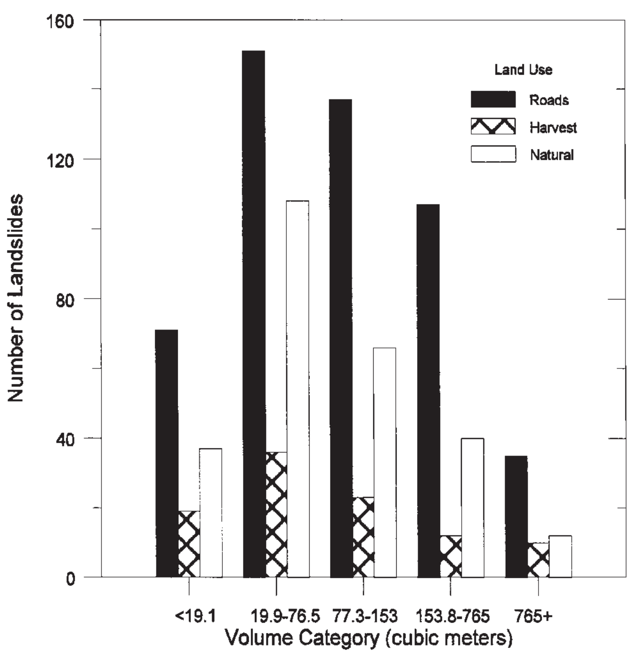


FIGURE 2 Landslide location map.



1 cu meter = 1.3 cu yd

FIGURE 3 Number of landslides by size and land use.

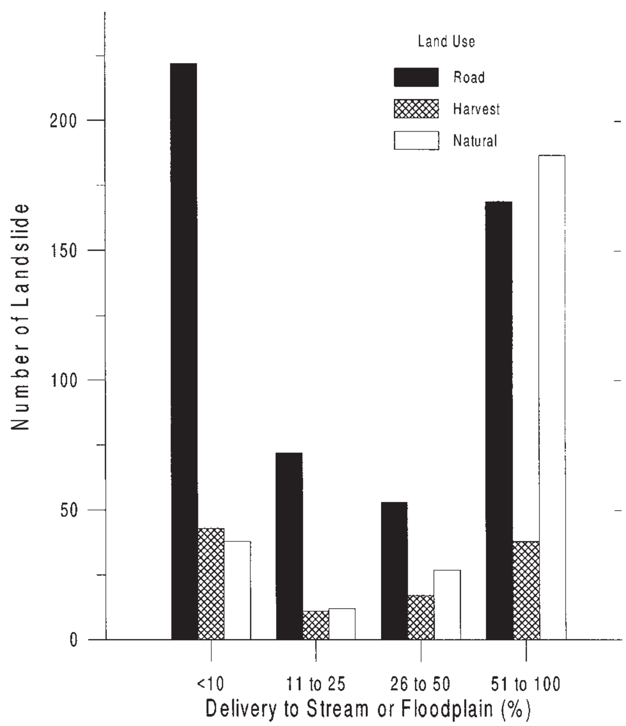


FIGURE 4 Delivery of sediment to stream or floodplain by land use.

TABLE 1 Number of Landslides by Geologic Parent Material and Land Use

Parent Material	Parent Material on CNF (%)	Number of Landslides						
		Total	per 1,000 ha[a]	Road	% of Roads on CNF	Landslides per km	Timber Harvest	Natural
Border	25	407	2.2	263	40	0.10	44	99
Batholith	39	358	1.3	163	43	0.06	42	150
Belt	14	90	0.89	69	12	0.09	17	4
Alluvium	8	6	0.10	4	2	0.04	2	0
Basalt	2	4	0.07	4	2	****	0	0
No data		42		19			5	14
Total	88[b]	907[c]		522			110	267

a. 1 hectare (ha) = 2.47 acres
b. 12 % of CNF geologic parent material is other than the listed parent materials.
c. Road, harvest, and natural landslides do not equal the total of 907 because 2 landslides were fire-related, and 6 were not classified as to land use.

Batholith consists primarily of granitics which are commonly deeply weathered and have grussic soils.

Border are high grade metamorphic rocks with interbedded schists, gneisses, impure quartzites and pegmatites. Typically are deeply weathered with 10 to 20% mica and have low cohesionless strength.

Belt rocks are weakly metamorphosed containing clean quartzites, argillites, siltites, and carbonates. Typically contain large percentage of angular particles which increases shear strength.

Basalts are layered volcanics which vary from hard weakly weathered to extensively weathered. Typically are fine grained and cohesive.

Alluvium results from surface erosion and deposition over geologic time and is dominated by ancient deposits associated with basalt flows. These lands have old, well developed, silty soils and commonly have seasonally perched groundwater tables over fragipans. Range in size from fine silts to coarse gravels, cobbles and boulders.

TABLE 2 Landslide Occurrence by Elevation and Land Use

Elevation Range (meters)[a]	Portion of CNF in Elev Range (%)	Number of Landslides				
		Total	Per 1,000 hectares[b]	Road Related	Timber Related	Natural
< 610	1	20	4.08	11	5	4
610 to 762	2	29	2.20	14	6	9
762 to 914	3	81	3.66	24	5	51
914 to 1067	6	184	4.09	115	20	47
1067 to 1219	11	203	2.75	127	19	53
1219 to 1372	14	206	2.08	139	31	35
1372 to 1524	16	137	1.22	73	21	43
1524 to 1676	16	32	0.31	13	2	17
1676 to 1829	14	5	0.12	1	0	4
1829 to 1981	17	1	0.00	0	0	2
No Data		9		5	1	3
Total	100	907[c]		522	110	267

a. 1 meter = 3.28 feet
b. 1 hectare = 2.47 acres
c. Road, harvest, and natural landslides do not equal the total of 907 because 2 landslides were fire-related, and 6 were not classified as to land use.

TABLE 3 Landslide Occurrence by Aspect and Land Use

Hillslope Aspect	Portion of CNF with Given Aspect (%)	Number of Landslides				
		Total	Per 1,000 hectares[a]	Road Related	Timber Harvest Related	Natural
North	11	39	0.52	21	7	10
Northeast	11	40	0.52	25	11	3
East	13	78	0.89	46	1	29
Southeast	13	86	0.94	47	8	30
South	12	200	2.47	94	25	80
Southwest	12	187	2.20	100	21	65
West	15	187	1.83	127	26	34
Northwest	14	75	0.77	52	9	14
No Data		15		10	2	2
Total	100	907[b]		522	110	267

a. 1 hectare = 2.47 acres
b. Road, harvest, and natural landslides do not equal the total of 907 because 2 landslides were fire-related, and 6 were not classified as to land use.

Historical Comparison

A comparison was made with the last significant storm and landslide event on the CNF in 1974, which was reported by Megahan et al. (*6*). The purpose of the comparison was to evaluate whether the landslide effects were generally proportional to the storm events or if the landscape response was becoming increasingly severe.

The authors estimated that the total precipitation plus snowmelt was approximately the same for the January 1974 and February 1996 events. The average total precipitation on the CNF for the November and December 1995 and the February 1996 storms was approximately 266.7 mm (10.5 in.) versus approximately 76.2 mm (3.0 in.) for the January 1974 event.

From Table 6, it can be seen that the average landslide was larger in 1974 than in 1995–1996, but the total volume, volume delivered to streams, and percentage of landslide volume delivered to stream channels were greater in 1995–1996, with approximately 38 percent of the volume delivered from the two large natural landslides.

TABLE 4 Number of Landslides by Hillside Steepness and Land Use

Hillside Steepness (%)	Portion of CNF with Given Steepness (%)	Number of Landslides				
		Total	Per 1,000 hectares[a]	Road Related	Timber Harvest Related	Natural
< 20	19	6	0.05	5	0	1
21 to 25	9	6	0.10	4	1	1
26 to 30	10	15	0.20	10	2	3
31 to 35	11	23	0.30	19	2	2
36 to 40	10	66	0.91	52	7	6
41 to 45	10	70	1.06	57	9	4
46 to 50	8	105	1.80	57	19	29
51 to 55	7	71	1.46	42	15	14
> 56	15	527	4.94	262	55	205
No Data		18		14	0	2
Total	100	907[b]		522	110	267

a.1 hectare = 2.47 acres
b. Number of Road, timber harvest , and natural landslides do not equal the total of 907 because 2 landslides were fire-related, and 6 were not classified as to land use.

TABLE 5 Landslides by Landform and Land Use

Landform	Portion of CNF with Given Landform (%)	Number of Landslides					
		Total	Per 1,000 hectares[a]	Road Related	Per km[b]	Timber Harvest Related	Natural
Breaklands	24	507	2.77	247	0.20	51	192
Mountain Slopes	15	149	1.33	106	0.04	24	20
Mountain Ridge	18	38	0.27	23	0.02	6	11
Gentle Hills	25	87	0.47	77	0.02	4	3
Mass Wasting	2	64	4.25	42	0.25	15	7
Valley	2	26	1.73	16	0.04	6	3
Total	86	871[c]		511[c]		106[c]	236[c]

a. 1 hectare = 2.47 acres
b. 1 km, kilometer = 0.62 miles
c. The landforms shown do not include all landforms on the C NF with landslides, and therefore, the number of landslides for total, road related, timber harvest related, and natural do not equal the total number for each category.

Landforms are used by the CNF to aggregate areas with common local relief, vegetative patterns, slope shape, slope gradient, and low order stream characteristics.

Breaklands are oversteepened slopes resulting from uplifting of the land surface and subsequent downcutting of rivers and streams. Hill slopes often exceed 60% and bedrock is moderately to weakly weathered.

Mountain Slopes have been formed by fluvial and colluvial processes. Ridges are generally convex and sideslopes straight. Hill slopes range from 35-60% and bedrock weathering is variable with weakly to moderately developed soils.

Mountain Ridges are broad convex slopes commonly occurring above mountain slopes and adjacent to steep glaciated terrain. Primarily formed by physical weathering and periglacial frost churning. Hill slopes range from 5-40%. Soils contain large percentage of coarse fragments and are highly permeable.

Gentle Hills consist primarily of gently to moderately sloping hills with less than 300 ft relief. Hill slopes are 20-40% with deep soils and extensively weathered bedrock.

Mass Wasting landforms contain historic rotational and translational landslides resulting in hummocky topography with 20-60% side slopes.

Valley landforms include both recent terraces and high terrace remnants, debris fans and colluvium. Hill slopes are typically up to 30% on terraces and fans, and up to 60% on toeslopes and eroded faces of terrace remnants.

Table 7 indicates that the landslide incident rates for the road, harvest, and combination of the natural and fire categories are remarkably close for the 1974 and 1995–1996 flood and landslide episodes.

Natural Background Sediment Rate

Wilson et al. (*7*) reported an average annual sediment yield of 85.6 kN/km^2 (25 tons/m^2) for undisturbed drainages on the CNF. The natural sediment yield resulted from in-channel transport of material that had originated from surface erosion of fire-denuded landscapes and natural mass wasting. Wilson et al. estimated the natural sediment loading at 20 percent from erosion of landscapes denuded by historic fires and 80 percent from natural landslides.

Nick Gerhardt (Nez Perce National Forest hydrologist, personal communication) obtained an average annual sediment yield of 92.7 kN/km^2 (27 tons/m^2) for the Selway River drainage near its confluence with the Lochsa River. The Selway River drainage had little timber harvest and few roads above the sampling location; consequently, these results should approximate the natural background sediment rate. The value agrees closely with the estimate of Wilson et al. (*7*).

Based on an area of 675 000 ha (1.667 million acres) for this study and a sediment density of 17.46 kN/m^3 (110 pcf), the natural background rate caused by natural landslides was estimated to be 30600 m^3 (40,000 yd^3) per year. Table 6 gives the incremental sediment delivery to streams above natural baseline for the 1974 and 1995–1996 landslide events. The total sediment delivered for the

TABLE 6 Landslide Characteristics—Comparison of 1974 Study and 1995–1996 Study

Year	Total Number of Landslides	Ave Size (m³)[a]	Total Volume (m³)	Delivered Volume (m³)	Delivery (%)	Ratio of Delivered Storm Sediment to Natural Background Sediment Loading[b]
1974[c]	214	1,262	270,000	86,000	32	2.8
1995-96 Total	907	589	535,000	306,000	57	10
1995-96 Roads	522	369	193,000	76,000	25	2.5
1995-96 Natural	267	1,183	316,000	217,000	71	7.1
1995-96 Harvest	110	243	27,000	12,000	4	0.4

a. 1 cubic meter (m³) = 1.31 cubic yards
b. Natural background sediment due to landslides estimated = 30,600 cubic meters.
c. Note that the 1974 study covered 80% of the 1995-1996 study area.

1974 and 1995–1996 events was approximately 3 to 10 times the annual natural background landslide sediment.

It was recognized that sediment loading to the streams across the CNF was not uniform and that the relative long-term impacts on fisheries from chronic, spatially continuous sediment loading would be different from that of episodic, spatially patchy sediment loading. The relative impacts of chronic, spatially continuous versus episodic, spatially patchy sediment loading were beyond the scope of this study. The value of 10 times the background rate of sediment loading assumed the sediment was uniformly spread over the Clearwater basin, which it clearly was not. Some watersheds were heavily affected, whereas others were largely unaffected by the landslides (Figure 2). The sediment delivery for selected watersheds was analyzed, and it was found that the sediment delivered varied from 5 to 270 times the background rate for selected watersheds with high landslide rates. The highest rate was for a single drainage, which contained a single landslide of 153 000 m³ (200,000 yd³). A random selection of 10 percent of the named watersheds across the CNF gave a range of 0.04 to 9.7 times the estimated background rate.

It is evident that the variation was observed across the range of scales from the size of a channel confluence to the size of a river basin. The impacts vary from sediment inundation to sediment impoverishment where landslides have essentially scoured a channel to bedrock.

TABLE 7 Landslides by Land Use—Comparisons of 1974 Study and 1995–1996 Study

Land Use	1974 (%)	1995-96 (%)
Roads	58	57
Natural	3[a]	29
Harvest	12	12
Fire	27	2[b]
Total	100	100

a. In complete survey of CNF
b. Very small acreage burned in recent years in area impacted by storm.

Evaluation of Current Road Construction Standards

The road construction practices observed by the authors varied from sidecast construction, prone to fill failures, to roads that had been located by geotechnical personnel to avoid landslide hazards and were adequately designed and constructed. The authors reviewed 9.65 km (6 mi) of roads constructed in problematic land types where the necessary skills were applied to location, design, and construction. The authors found no road-related landslides where adequate geotechnical input had been used.

Evaluation of Road-Obliteration Projects

The authors field reviewed 9.65 km (6 mi) of obliterated roads. The treatments ranged from merely closing the road to traffic to full recontouring (pulling the fillslopes onto the road surface to restore the slope to the original contours). At the time of the 1995–1996 events, the obliteration program had treated 59.5 km (37 mi) of historically unstable roads. On the basis of the general results of this study, 10 landslides would have been predicted for 9.65 km (6 mi) of road on those landforms. The authors were not aware of any road-associated landslides occurring on the treated roads. Slides did occur on adjacent untreated roads on the same landforms. On the basis of these observations, it was concluded that road obliteration has successfully reduced road-related landslides.

Stream Response

Stream responses to the flood and landslide events were found to depend largely on landform, parent material, and stream size. Landslides and flood flows negatively affected small streams by significantly widening their channels and scouring out acting large organic debris. Small streams did, however, show a reduced level of cobble embeddedness and increased average depth compared with preflood landslide conditions. Large streams were negatively affected by landslides and flood flows through stream channel widening and increased levels of cobble embeddedness when compared with historic conditions. No significant improvements were found on large stream channels when compared with pre-post conditions on the same stream reach. General comparisons of flood-only stream reaches with flood and landslide reaches showed that the flood and landslide reaches had, on average, significantly lower ratios of width to depth and greater pool area, yet had decreased channel stability, as indicated by the Pfankuch index. Flood and landslide reaches were generally deemed "less habitable" for benthic macroinvertebrates than reaches affected only by flood flows.

The existence of a road within a drainage was not found to be consistently related to the level of landslide impacts on streams.

Recommendations for Reducing Landslides

The following recommendations for reducing landslides on the CNF resulting from roads and timber harvest are based on the observations of the 1995–1996 inventory of the landslides, the authors' field reviews, and the authors' collective experiences.

Roads

A systematic inventory of the road network should be completed. The inventory should include information on all construction, reconstruction, maintenance, decommissioning, and use activities on the roads. The inventory, together with a geographic information system (GIS) screening predicated on the five landslide risk factors identified in this study, will allow location, prescription, and ranking of roads for maintenance, reconstruction, or decommissioning.

The decision to maintain or decommission a road should be based on the maintenance required, transportation system needs, and potential environmental risks. Longer maintenance intervals require more conservative maintenance or decommissioning prescriptions. For any road permanently closed to vehicle use, culverts should be removed and provisions made to ensure control of surface water. For a closed road, the maintenance interval might be many years, although periodic inspections will still be needed to assess the road prism stability, unless the road prism has been recontoured.

The rate of occurrence of landslides on new roads can also be reduced by GIS screening of the project areas using the five landslide risk indicators and then scrupulously adhering to appropriate design and construction practices. The following practices should be observed:

- Avoid high-risk areas when possible.
- If necessary to have a road on a slope steeper than 55 percent, full bench and end haul.
- Perform geotechnical investigations to avoid landslide hazards or to obtain low-risk designs to mitigate the effects of the hazards, especially in areas that have potential for high groundwater levels.
- Because most road-related landslides in the study were found to have been fill failures, the road should be designed to control surface flows, and thus to avoid discharging accumulations of water on fills or other areas that have potential to fail because of the addition of water. The design should include backup drainage design features. In the event that culverts, ditches, or other drainage features fail to handle the water, these backup features will direct the overflow to areas of least impact rather than onto large fills or other potentially unstable areas.
- Construction of critical fills should include subexcavation of weak foundation materials and adequate compaction to improve the fill stability, reduce settlement deformation, and resist erosion.

Harvest Areas

Although landslide rates from timber harvest areas were not large in the 1995–1996 study, others (*5*) have found them to be significant, with the important factor being loss of root strength. The five landslide indicators can be used to identify high-risk portions of areas considered for timber harvest. Timber harvest treatments that maintain root strength can be used to reduce landside hazards.

SUMMARY AND CONCLUSIONS

- Of the 907 landslides on the CNF in this study, 58 percent were road related, 29 percent were natural, and 12 percent were associated with timber harvest. The total landslide volume was estimated to be 535 500 m^3 (700,000 yd^3), of which 306 000 m^3 (400,000 yd^3) were delivered to streams.
- Five landslide indicators that can be used to delineate high-risk areas were identified in this study. These factors are geologic parent material, elevation, slope aspect, hillside steepness, and landform.
- The findings of this study were similar to those of the 1974 study on the CNF. The total landslide volume delivered to streams in the 1974 event was approximately three times the natural annual landslide background sediment rate. The 1995–1996 events delivered 10 times the natural annual landslide background rate, with natural landslides contributing 70 percent of the sediment delivered to stream channels.
- Evaluation of landslide effects was confounded by stream size (e.g., smaller streams were in steeper terrain); those streams therefore had more energy and scouring capability. Stream channels and banks were destabilized after landslides, but channels generally became deeper, wider, and more unstable, and they had larger stream channel particle sizes after landslides. Larger streams had lower gradients and less energy, resulting in more deposition as well as less stable channels and banks after the flood and landslide flows.
- Study results emphasized the value of conducting evaluations on identical reaches of streams before and after the flood and landslide events. Comparison of parameters between paired streams or between clusters of streams with similar characteristics (where impacts occurred in some and not in others) is frustrated by the large range of variation of parameters between different streams.
- The CNF road obliteration program appears to have been effective in reducing road-related landslides.
- Use of the five landslide risk indicators identified in the study can be used to highlight high hazard areas. For new roads, they can be used to avoid high hazard areas or to develop site-specific road designs and specifications. For existing roads, they can help set priorities for maintenance and suggest appropriate management ranging from year-round use to complete recontouring. For planned timber harvest units, the five indicators can be used to avoid unstable areas or assist in the planning of timber harvest activities to minimize landslide hazard.
- The authors found no road-related landslides where adequate geotechnical input had been used.

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